PASJ: Publ. Astron. Soc. Japan , 1–??,

A Synchronized Variation of the 6.7 GHz Methanol Maser in Cepheus A

Koichiro Sugiyama,[1] Kenta Fujisawa,[1,2] Akihiro Doi,[3] Mareki Honma,[4,5] Yasuko Isono,[1]
Hideyuki Kobayashi,[4,6] Nanako Mochizuki,[3] and Yasuhiro Murata[3,7]
[1] *Graduate school of Science and Engineering, Yamaguchi University, 1677-1 Yoshida, Yamaguchi, Yamaguchi 753-8512*
[2] *Department of Physics, Faculty of Science, Yamaguchi University, 1677-1 Yoshida, Yamaguchi, Yamaguchi 753-8512*
[3] *The Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency, 3-1-1 Yoshinodai, Sagamihara, Kanagawa 229-8510*
[4] *VERA Project, National Astronomical Observatory of Japan, 2-21-1 Osawa, Mitaka, Tokyo 181-8588*
[5] *Department of Astronomical Science, Graduate University for Advanced Studies, 2-21-1 Osawa, Mitaka, Tokyo 181-8588*
[6] *Mizusawa VERA Observatory, 2-12 Hoshigaoka, Mizusawa, Iwate 023-0861*
[7] *Department of Space and Astronautical Science, The Graduate University for Advanced Studies, 3-1-1 Yoshinodai, Sagamihara, Kanagawa 229-8510*
m005wa@yamaguchi-u.ac.jp

(Received 2008 March 8; accepted 2008 April 27)

Abstract

We present the results of daily monitoring of 6.7 GHz methanol maser in Cepheus A (Cep A) using Yamaguchi 32-m radio telescope as well as the results of imaging observations conducted with the JVN (Japanese VLBI Network). We indentified five spectral features, which are grouped into red-shifted (-1.9 and -2.7 km s^{-1}) and blue-shifted (-3.8, -4.2, and -4.9 km s^{-1}), and we detected rapid variabilities of these maser features within a monitoring period of 81 days. The red-shifted features decreased in flux density to 50% of its initial value, while the flux density of the blue-shifted features rapidly increased within a 30 days. The time variation of these maser features showed two remarkable properties; synchronization and anti-correlation between the red-shifted and the blue-shifted. The spatial distribution of the maser spots obtained by the JVN observation showed an arclike structure with a scale of ~1400 AU, and separations of the five maser features were found to be larger than 100 AU. The absolute position of the methanol maser was also obtained based on the phase-referencing observations, and the arclike structure were found to be associated with the Cep A-HW2 object, with the elongation of the arclike structure nearly perpendicularly to the radio continuum jet from the Cep A-HW2 object. These properties of the masers, namely, the synchronization of flux variation, and the spectral and spatial isolation of features, suggest that the collisional excitation by shock wave from a common exciting source is unlikely. Instead, the synchronized time variation of the masers can be explained if all the maser features are excited by infrared radiation from dust which is heated by a common exciting source with a rapid variability.

Key words: masers: methanol — ISM: H II regions — ISM: individual (Cepheus A)

1. Introduction

The $5_1 \rightarrow 6_0 A^+$ methanol maser transition at 6.7 GHz has the strongest flux densities among methanol maser lines. The methanol maser emission is thought to be produced by radiative excitation in an infrared radiation field, which is formed by dust near the protostar with a temperature of ~100-200 K (Sobolev et al. 1997; Sutton et al. 2001; Cragg et al. 2005). Some sources, however, are associated with shocked gas (Walsh et al. 1998; De Buizer 2003; Dodson et al. 2004). Collisional excitation by shock wave may produce the methanol maser emission.

A number of 6.7 GHz methanol masers have been found to exhibit long-term variability. Caswell et al. (1995) found that the sources vary on a time-scale of several months. Szymczak et al. (2000) showed that about 65% of methanol maser in their sample exhibit moderate or strong variability on time-scales of about four and eight years. A long-term monitoring program to investigate the variability of 54 methanol maser sources at 6.7 GHz has been conducted using the Hartebeesthoek 26-m radio telescope by Goedhart et al. (2004). They divided the variable sources into six types according to the behavior of the variability. For G9.62+0.20E in their sample, the periodic variations associated with massive star formation were discovered for the first time (Goedhart et al. 2003). The Very Long Baseline Interferometer (VLBI) monitoring at seven epochs over three months for G9.62+0.20E was conducted within the period of the time variation (Goedhart et al. 2005). No appearance of new spots and no change in morphology was found, suggesting that the flares were caused by a change in either the seed or pump photon

levels. They proposed a binary system as an origin of the periodic flares. MacLeod & Gaylard (1996) continuously observed G 351.78−0.54, and found flares at least seven times with time delays in the range 10-35 days between the variability of red-shifted spectral feature and blue-shifted feature. They discussed the delay, which can possibly be explained in terms of light-crossing time due to the spatial distribution of spots.

We have conducted daily monitoring for some maser sources to investigate a short time-scale variability with Yamaguchi 32-m radio telescope. Cepheus A (Cep A) was observed as one of our sample sources. Cep A is a CO condensation at a distance of 725 pc (Johnson 1957) and some radio continuum sources were detected. Methanol masers are associated with Cep A-HW2 defined by Hughes & Wouterloot (1984), which is the brightest radio continuum source detected in the region. The HW2 object has a radio continuum jet along a position angle (PA) of $\sim 45°$ (Rodriguez et al. 1994; Hughes et al. 1995; Torrelles et al. 1996, 1998; Curiel et al. 2006). Based on submillimeter observations of both dust and CH_3CN line emissions, a flattened disklike structure was found (Patel et al. 2005). The structure has a size of about 1000 AU and is perpendicular to the jet. Recently, it is revealed that NH_3 and SO_2 line emissions coincided with the CH_3CN disk, although the SO_2 structure was about 2 times smaller (Torrelles et al. 2007; Jiménez-Serra et al. 2007). The 22.2 GHz water masers observed by Torrelles et al. (1996) were distributed in an elongated structure perpendicular to the radio jet, which possibly trace the circumstellar disk around the HW2 object. The water maser has a spatial distribution similar to the SO_2 disk. The methanol maser at 6.7 GHz in Cep A shows variability. It was 1420 Jy in 1991 (Menten 1991), but 815 Jy in 1999 (Szymczak et al. 2000). Galt (2003) has found that the amplitude ratio of the lines at a radial velocity of -3.8 km s^{-1} and -4.2 km s^{-1} varies from 1.4 to 0.8 over two years. The spatial distribution of the masers at 6.7 GHz for Cep A have been already reported (Sugiyama et al. 2008) with the Japanese VLBI Network (JVN; Doi et al. 2006). However, the image quality was not enough to investigate the relationship the spectral features and the spatial distribution.

In this paper, we present the spectral variability with the spectral monitoring observations and a new VLBI map. In section 2, we describe the details of these observations and data reduction, and the results are presented in section 3. In section 4, we discuss interpretations of the rapid variability and excitation mechanism of this maser in Cep A.

2. Observations and Data Reduction

2.1. *Spectral Monitoring*

The daily monitoring program with Yamaguchi 32-m radio telescope was made from August 4 (corresponding to the days of year (DOY) 216) to October 24 (DOY 297), 2007. The full-width at half maximum (FWHM) of the beam is 5 arcmin at 6.7 GHz. The pointing error of the antenna is smaller than 1 arcmin. The spectrometer consists of the IP-VLBI system (Kondo et al. 2003) and a software spectrometer. Both left and right circular polarizations were recorded with 2-bit sampling. The recorded data with a bandwidth of 4 MHz, covering a velocity range of 180 km s^{-1}, were divided into 4096 channels, yielding a velocity resolution of 0.044 km s^{-1}. The integration time is 14 minutes until DOY 244, and then 10 minutes from DOY 245. The rms noise level was typically 1.2 Jy and 1.4 Jy with an integration time of 14 min and 10 min, respectively. An amplitude and a gain calibration was performed by measuring the system noise temperatures by injecting the signal from noise-sources with known temperatures. The accuracy of the calibration was estimated to be 10%. The stability of the system was checked by daily monitoring G12.91−0.26 methanol maser emission, which showed relatively small variability in the sample of Goedhart et al. (2004).

2.2. *VLBI Observation*

A VLBI observation at 6.7 GHz of Cep A was made on September 9 2006 from 15:00 to 22:00 UT with four telescopes (Yamaguchi 32-m, Usuda 64-m, VERA-Mizusawa 20-m, and VERA-Ishigaki 20-m) of the JVN. The projected baselines covered from 9 Mλ (Usuda–Mizusawa) to 50 Mλ (Mizusawa–Ishigaki), corresponding to the fringe spacing of 23 mas and 4.1 mas, respectively. Left-circular polarization was received at Yamaguchi and Usuda stations, while linear polarization was received at Mizusawa and Ishigaki stations. A special amplitude calibration for different polarizations was made by the same procedure as described in Sugiyama et al. (2008). The data were recorded on magnetic tapes using the VSOP-terminal system at a data rate of 128 Mbps with 2-bit quantization and 2 channels, and correlated at the Mitaka FX correlator (Shibata et al. 1998). From the recorded 32 MHz bandwidth, 2 MHz (6668-6670 MHz) was divided into 512 channels for maser reduction, yielding a velocity resolution of 0.176 km s^{-1}. This is four times broader than that of the single-dish observation.

A continuum source J2302+6405 ($2\overset{\circ}{.}19$ from Cep A), whose coordinate is known with an accuracy of 0.62 mas in the third VLBA Calibrator Survey (VCS3) catalog (Petrov et al. 2005), was used as a phase reference calibrator. We alternately observed the Cep A methanol maser and the continuum source with switching observational mode with a cycle of 5 min (2 min on Cep A and 1.6 min on the continuum source). Cep A was sometimes continuously observed for more than 30-min to improve the UV-coverage. The total on-source times were 2.8 hours and 0.7 hours for Cep A and J2302+6405, respectively. Bright continuum sources, 3C 454.3 and 3C 84, were also observed every one and half hours for clock and bandpass calibration. The synthesized beam has a size of 9.0×3.5 mas with a PA of $-70°$.

The data were reduced using the Astronomical Image Processing System (AIPS: Greisen 2003) and the Difmap software (Shepherd 1997). The visibilities of all velocity channels were phase-referenced to the reference maser

spot at LSR velocity of -2.64 km s^{-1}, which is the brightest spot. The absolute coordinate of the spot of -2.64 km s^{-1} was obtained by applying the solution of phase for the velocity channel to the phase reference source J2302+6405.

3. Results

3.1. Spectral Variability

We detected a rapid variability in the spectrum of 6.7 GHz methanol maser of Cep A. Five spectral features, at radial velocity of -1.9, -2.7, -3.8, -4.2, and -4.9 km s^{-1}, were identified during the whole observing period as shown in figure 1. The maser features were labeled as I, II, III, IV, and V, respectively. The feature II showed a shoulder at -2.5 km s^{-1}, corresponding a second component. Since we could not clearly distinguish the two components of feature II, the second component is not discussed in this paper.

The maser features are divided into two groups; two red-shifted features (I, II), and three blue-shifted features (III, IV, V). These two groups are clearly separated in the spectrum. They also exhibited different trends of variation as shown in figure 1b. For the first 30 days of the monitoring, the red-shifted group decreased to 50% of its initial value (feature II), while the blue-shifted group increased up to 300% (feature V). Correlation coefficients for all combinations of spectral features for the data from DOY 216 to 250 is shown in table 1. The absolute values of correlation coefficients are larger than 0.80, with only exception of 0.63 for I vs IV. The variation shows a strong correlation within each group, and an anti-correlation between two groups.

A trend of the variation suddenly changed at around DOY 250. The red-shifted group started to increase and the blue-shifted group started to decrease. The rate of variation was smaller than that of previous period. This change in the variation trend was clearly synchronized.

Correlation coefficients for the whole period are shown in table 2. The coefficients show essentially the same trends with those for the first period. The feature II shows a strong and positive correlation (0.89) with the feature I, while anti-correlation was seen with the features III, IV, and V. The correlation coefficients are -0.91, -0.50, and -0.68, respectively. Figure 2 shows the correlation plots for combinations with respect to the feature II. The positive (I) and anti-correlation (III, IV, V) is obvious.

Flux variation of feature IV and III are quite similar each other, but the variation of feature IV is slightly advanced to that of feature III. Cross-correlation of the time series of the features showed small time-delays. The largest delay is 6 days for II to IV, and the smallest is 1 day for II to III and V to IV. We ignored the feature I because of its small variation.

3.2. Spatial Distribution

With the VLBI observation, 117 spots of the methanol maser emission were detected. Peak intensities of the spots ranged from ∼650 mJy beam^{-1} to 122 Jy beam^{-1},

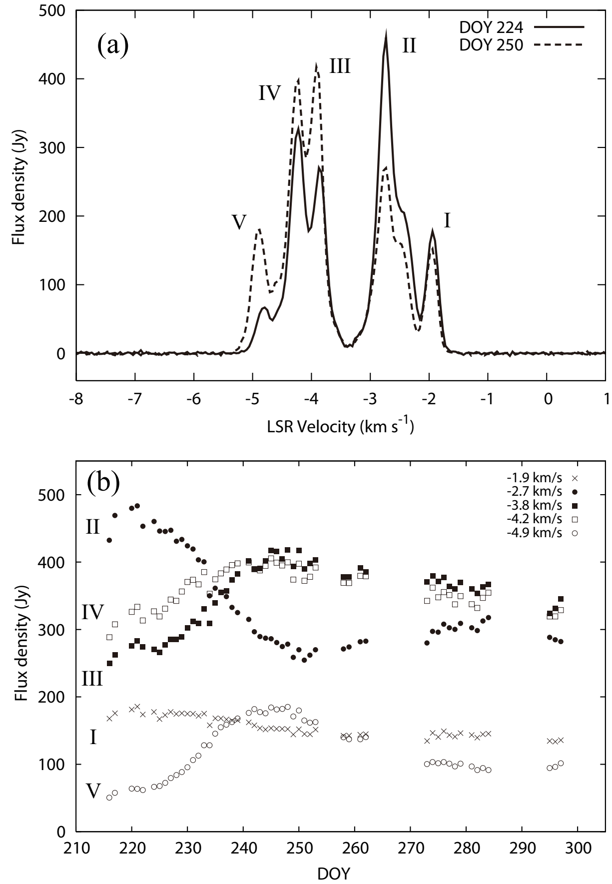

Fig. 1. The 6.7 GHz methanol maser in Cep A. The labels I, II, III, IV, and V correspond to each spectral feature in each panel. (a) The spectra obtained in the monitoring observations. The solid and dashed line shows the spectra obtained in DOY 224 and 250 observation, respectively. (b) Time variation of each spectral feature.

Table 1. Correlation coefficients from DOY 216 to 250

feature	feature			
	I	II	III	IV
II	0.94			
III	−0.83	−0.96		
IV	−0.63	−0.84	0.92	
V	−0.83	−0.97	0.98	0.94

Table 2. Correlation coefficients for all days

feature	feature			
	I	II	III	IV
II	0.89			
III	−0.65	−0.91		
IV	−0.08	−0.50	0.77	
V	−0.28	−0.68	0.84	0.92

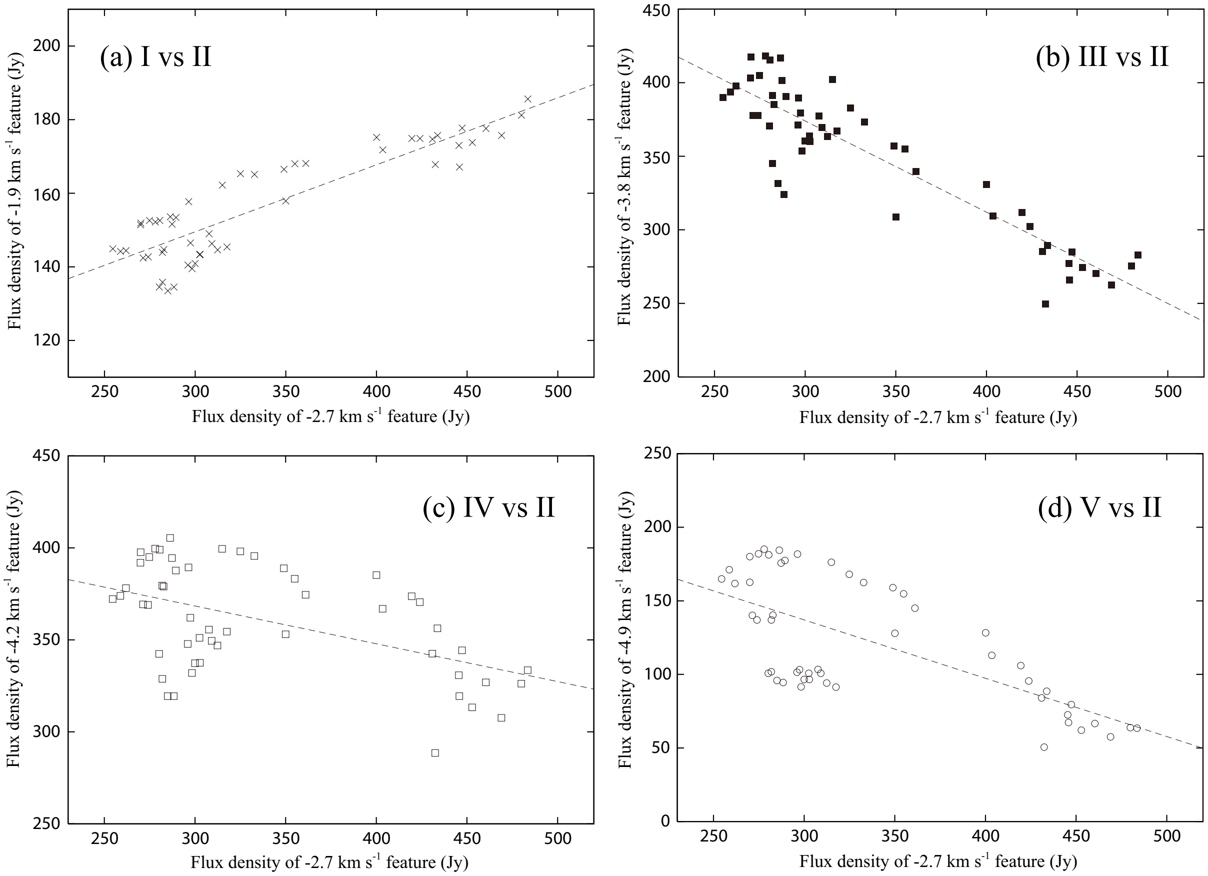

Fig. 2. The correlation plots with respect to the spectral feature II. The symbols in each panel correspond to the spectral features in figure 1b. The dashed lines in each panel indicate the best fits to the data.

while the rms of image noise (1σ) in a line-free channel was 160 mJy beam^{-1}. The correlated flux accounted for over 90% of the single-dish flux. The spatial distribution of the maser spots (figure 3) showed an arclike structure. The size from edge to edge of the arclike structure is $\sim$1900 mas or $\sim$1400 AU at a distance of 725 pc.

The absolute coordinate of the spot at -2.64 km s^{-1} obtained in our observation is α(J2000.0) $= 22^{\mathrm{h}}56^{\mathrm{m}}17.^{\mathrm{s}}90421$, δ(J2000.0) $= +62^\circ01'49.''5769$, with errors less than 1 mas. This is the origin of the image. The peak of 43 GHz continuum emission (star symbol), which may be an exciting source (Curiel et al. 2006), located near the center of the arclike structure of the 6.7 GHz methanol maser spots. The elongation of the arclike structure is nearly perpendicular to the radio jet. The overall distribution of the maser spots coincide with the CH_3CN and NH_3 disks (Patel et al. 2005; Torrelles et al. 2007) and the velocity range of the spots is similar to that of these disks, although a simple velocity gradient was not detected with the maser spots. The water maser disk reported by Torrelles et al. (1996) locates almost the same position with the methanol arclike structure, although the size of the water maser disk is about 2 times smaller. The ground-state hydroxyl masers around the HW2 object (Migenes et al. 1992; Bartkiewicz et al. 2005), whose internal proper motions were mainly directed away from the central source, are distributed surrounding the methanol maser distribution. The radial velocities of both masers (water: -27.3 to $+8.9$ km s^{-1}; hydroxyl: -25.2 to -0.6 km s^{-1}) cover the range of the methanol maser (-4.93 to -0.36 km s^{-1}).

The cluster of the spots locating near the origin of the VLBI map corresponds to the spectral features I and II, and a cluster locating at $0.''45$ east, $0.''10$ south from the origin corresponds to the feature II. The correspondences of the other clusters and the spectral features are as follows; the western cluster ($0.''30$ west, $0.''20$ north) is III, the eastern cluster ($1.''35$ east, $0.''20$ south) is IV, and the northern cluster ($0.''10$ east, $0.''50$ north) is V, respectively. The clusters II ($0.''45$ east, $0.''10$ south) and V were detected for the first time in VLBI observations. Some weak spots with radial velocities from -0.53 to -0.36 km s^{-1}, which are a part of the cluster II, were detected only in the VLBI observation, and not detected in the spectral observation with Yamaguchi 32-m telescope. The red-shifted (I, II) and the blue-shifted features (III, IV, V) are isolated in the spatial distribution by more than 100 AU, and the red-shifted features are surrounded by the blue-shifted features.

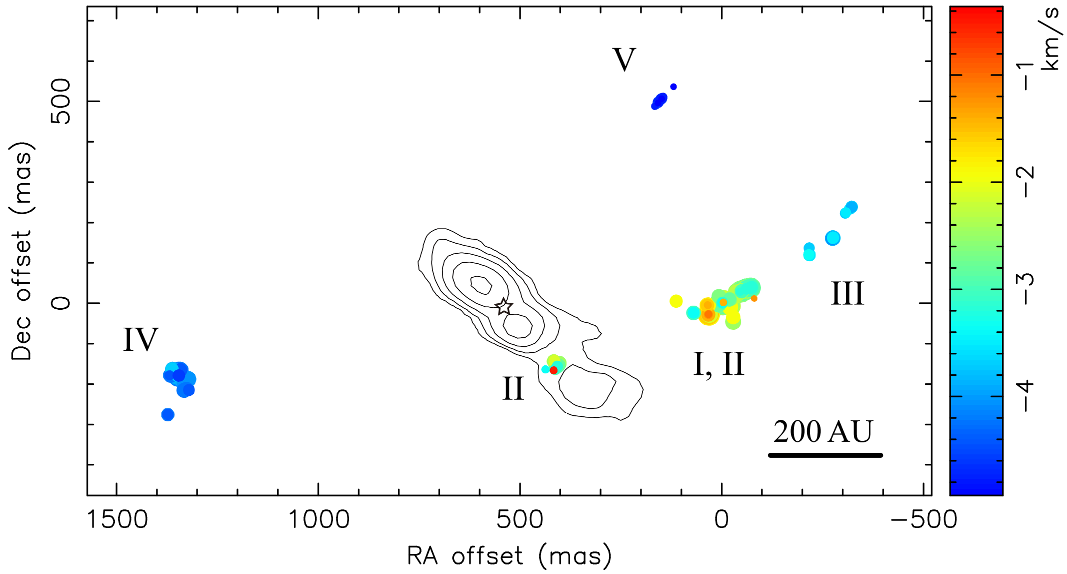

Fig. 3. A spatial distribution of the 6.7 GHz methanol maser spots (filled circle) of Cep A. The spot size and color indicates its peak intensity in logarithmic scale and its radial velocity (see color index at the right), respectively. The contours indicate the VLA 22 GHz continuum observed by Torrelles et al. (1998) and re-reduced by Gallimore et al. (2003). A star indicates the peak of 43 GHz continuum emission with the positional uncertainty of about 10 mas. It is thought as the location of an exciting source (Curiel et al. 2006). The origin of this map corresponds to the absolute coordinate of the 6.7 GHz methanol maser (α(J2000.0) = $22^{\rm h}56^{\rm m}17^{\rm s}.90421$, δ(J2000.0) = $+62^\circ 01' 49''.5769$) obtained by our observation.

4. Discussions

The time variation of the methanol maser features of Cep A was synchronized, and (anti-)correlated. The synchronized variation were occured at spatially isolated maser features. The separation of clusters is larger than 100 AU in the overall spatial distribution of ∼1400 AU, and it is not likely that there are some mechanical interactions between features that causes synchronized variation. The synchronized variation may be caused by shock wave from a central star, that is arrived at the clusters simultaneously. If we assume an outflow velocity of 4.5 km s^{-1} which corresponds to a radial velocity range of the Cep A methanol maser, it takes more than 1000 years to propagate through the spatial scale of 1000 AU. The synchronized arrival to the separated clusters with a time delay less than several days requires a very fine tuning of arrival time (6 days/1000 years ∼0.002%), which is highly unlikely. The synchronization, the spatial isolation and the spectral separation of the maser features suggest that it is difficult to excite the maser by collision in shock wave from a common exciting source.

These properties favor the widely accepted excitation model that the 6.7 GHz methanol masers is excited by infrared radiation from nearby warm dust (e.g., Sobolev et al. 1997). Infrared radiation from one variable exciting source is easy to explain the synchronized variation with the spatial isolation and the spectral separation. The exciting source might correspond to that one showed by Curiel et al. (2006). The bolometric luminosity of the Cep A region is about 2.5×10^4 $L_\odot$ (Evans et al. 1981). Assuming that half of this luminosity is attributed to the HW2 object (Rodriguez et al. 1994; Hughes et al. 1995), we derive a dust temperature of 110 K at 700 AU from the exciting source. The distance 700 AU is that from the supposed exciting source to the farthest maser spot. This temperature 110 K is consistent with the suitable temperature (∼100-200 K) of regions producing 6.7 GHz methanol maser (e.g., Cragg et al. 2005). This time variation model of one exciting source may be applicable to the periodic variations of the 6.7 GHz methanol maser for G9.62+0.20E.

The time variation of the Cep A methanol maser showed anti-correlation between the red-shifted and the blue-shifted features. A light-crossing time of ∼1400 AU is 8 light-day. It is consistent with the time-delays (1-6 days) in the cross-correlation of the flux variation of spectral features. However, the light-crossing time is too short to cause the anti-correlation with time-scale more than 20 days. The anti-correlation could be understood in terms of excitation environment. The 6.7 GHz methanol maser requires a suitable temperature range (∼100-200 K). Dust temperature is high at regions close to the exciting source, and is low at regions far from the source. If the exciting source increases its luminosity, the temperature near the source would be too high to produce the maser emission, while the temperature far from the source would be suitable to produce the maser. Although the 3-dimensional distribution of maser features is uncertain, the 2-dimensional distribution of the maser features of Cep A indicates that the red-shifted features are close to the supposed exciting source, and the blue-shifted features are far from it. With this spatial distribution, the anti-correlation of variation could be explained by the dust

temperature change caused by variability of the exciting source, i.e., during the period between DOY 216 and 250, the dust temperature at feature II, which is closer to the exciting source, increases beyond 200 K and out of the appropriate range for maser excitation, while the temperature at feature III, IV, and V increased from 110 K, which is nearly the minimum value of maser excitation, to produce stronger maser emission.

Additional observations are required to confirm this model, in particular to test if short time variation of luminosity occurs in the exciting source. The distribution of maser features is observed as a 2-dimensional projection. The velocity field would be a clue to understand the 3-dimensional structure of this region. We are conducting the VLBI monitoring observations to detect the internal proper motion of methanol maser spots, and the results will be reported in future.

5. Conclusion

We have detected a rapid variability of 6.7 GHz methanol maser of Cep A. Five spectral features are grouped into the red-shifted (-1.9 and -2.7 km s^{-1}) and the blue-shifted (-3.8, -4.2, and -4.9 km s^{-1}). These two groups are clearly separated in the spectrum. They also exhibited different trends of variation. The time variation of this maser features showed two remarkable properties; synchronization and anti-correlation between the red-shifted and the blue-shifted features. The spatial distribution of the maser spots obtained by the VLBI observation showed that maser spots of each feature are largely separated. The synchronization, the spectral and the spatial isolation suggest that the collisional excitation by shock wave from a common exciting source is unlikely. We discussed that the time variation of the Cep A methanol maser could be produced by one variable exciting source and this maser could be excited by radiation from the exciting source. It is possibly thought that the anti-correlation is caused by a variation of the dust temperature of the maser regions as a result of the distance to the exciting source, and the time variation of the exciting source's luminosity.

The authors wish to thank the JVN team for observing assistance and support. The authors also would like to thank the anonymous referee for many useful suggestions and comments, which improved this paper. The JVN project is led by the National Astronomical Observatory of Japan (NAOJ) that is a branch of the National Institutes of Natural Sciences (NINS), Hokkaido University, Tsukuba University, Gifu University, Yamaguchi University, and Kagoshima University, in cooperation with Geographical Survey Institute (GSI), the Japan Aerospace Exploration Agency (JAXA), and the National Institute of Information and Communications Technology (NICT).

References

Bartkiewicz, A., Szymczak, M., Cohen, R. J., & Richards, A. M. S. 2005, MNRAS, 361, 623
Caswell, J. L., Vaile, R. A., Ellingsen, S. P., Whiteoak, J. B., & Norris, R. P. 1995, MNRAS, 272, 96
Cragg, D. M., Sobolev, A. M., & Godfrey, P. D. 2005, MNRAS, 360, 533
Curiel, S., et al. 2006, ApJ, 638, 878
De Buizer, J. M. 2003, MNRAS, 341, 277
Dodson, R., Ojha, R., & Ellingsen, S. P. 2004, MNRAS, 351, 779
Doi, A., et al. 2006, in Proc. 8th European VLBI Network Symp. (Torun), p.71
Evans, N. J., II, et al. 1981, ApJ, 244, 115
Gallimore, J. F., Cool, R. J., Thornley, M. D., & McMullin, J. 2003, ApJ, 586, 306
Galt, J. 2003, AJ, 126, 1967
Goedhart, S., Gaylard, M. J., & van der Walt, D. J. 2003, MNRAS, 339, L33
Goedhart, S., Gaylard, M. J., & van der Walt, D. J. 2004, MNRAS, 355, 553
Goedhart, S., Minier, V., Gaylard, M. J., & van der Walt, D. J. 2005, MNRAS, 356, 839
Greisen, E. W. 2003, Information Handling in Astronomy - Historical Vistas, 109
Hughes, V. A., & Wouterloot, J. G. A. 1984, ApJ, 276, 204
Hughes, V. A., Cohen, R. J., & Garrington, S. 1995, MNRAS, 272, 469
Jiménez-Serra, I., Martín-Pintado, J., Rodríguez-Franco, A., Chandler, C., Comito, C., & Schilke, P. 2007, ApJ, 661, L187
Johnson, H. L. 1957, ApJ, 126, 121
Kondo, T., Koyama, Y., Nakajima, J., Sekido, M., & Osaki, H. 2003, Astronomical Society of the Pacific Conference Series, 306, 205
MacLeod, G. C., & Gaylard, M. J. 1996, MNRAS, 280, 868
Menten, K. M. 1991, ApJ, 380, L75
Migenes, V., Cohen, R. J., & Brebner, G. C. 1992, MNRAS, 254, 501
Patel, N. A., et al. 2005, Nature, 437, 109
Petrov, L., Kovalev, Y. Y., Fomalont, E., & Gordon, D. 2005, AJ, 129, 1163
Rodriguez, L. F., Garay, G., Curiel, S., Ramirez, S., Torrelles, J. M., Gomez, Y., & Velazquez, A. 1994, ApJ, 430, L65
Shepherd, M. C. 1997, ASP Conf. Ser. 125: Astronomical Data Analysis Software and Systems VI, 125, 77
Shibata, K. M., Kameno, S., Inoue, M., & Kobayashi, H. 1998, ASP Conf. Ser. 144: IAU Colloq. 164: Radio Emission from Galactic and Extragalactic Compact Sources, 144, 413
Sobolev, A. M., Cragg, D. M., & Godfrey, P. D. 1997, MNRAS, 288, L39
Sugiyama, K., Fujisawa, K., Doi, A., Honma, M., Kobayashi, H., Bushimata, T., Mochizuki, N., & Murata, Y. 2008, PASJ, 60, 23
Sutton, E. C., Sobolev, A. M., Ellingsen, S. P., Cragg, D. M., Mehringer, D. M., Ostrovskii, A. B., & Godfrey, P. D. 2001, ApJ, 554, 173
Szymczak, M., Hrynek, G., & Kus, A. J. 2000, A&AS, 143, 269
Torrelles, J. M., Gómez, J. F., Rodríguez, L. F., Curiel, S., Ho, P. T. P., & Garay, G. 1996, ApJ, 457, L107
Torrelles, J. M., Patel, N. A., Curiel, S., Ho, P. T. P., Garay, G., & Rodríguez, L. F. 2007, ApJ, 666, L37

Torrelles, J. M., Gómez, J. F., Garay, G., Rodríguez, L. F., Curiel, S., Cohen, R. J., & Ho, P. T. P. 1998, ApJ, 509, 262

Walsh, A. J., Burton, M. G., Hyland, A. R., & Robinson, G. 1998, MNRAS, 301, 640